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Multiscale Technicolor and Top Production

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Abstract

Pair–production of heavy top quarks at the Tevatron Collider is significantly enhanced by the color–octet technipion, η_T, occurring in multiscale models of walking technicolor. We discuss $\bar{t}t$ rates for $m_t = 170\,\mathrm{GeV}$ and $M_{\eta_T} = 400 - 500\,\mathrm{GeV}$. Multiscale models also have color–octet technirho states in the mass range $200 - 600\,\mathrm{GeV}$ that appear as resonances in dijet production and technipion pair–production.

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Over the past year there has been intense searches for the top quark by the CDF [1] and DØ [2] collaborations using data obtained during the recent high–luminosity run of the Tevatron Collider at Fermilab.[1] Two main signatures have been sought: (1) Events with two isolated high–energy leptons ($e^\pm$ and $\mu^\pm$) and large missing transverse energy ($\not\!\!E_T$); (2) Events with an isolated lepton associated with multijets (≥ 3) and large $\not\!\!E_T$. Both are signatures of the standard–model processes expected at the Tevatron: QCD production of $\bar{t}t$ with each top–quark decaying as $t \to Wb \to (\ell + \not\!\!E_T + \mathrm{jet})$ or 3 jets. So far, a clear signal for this standard top–quark production has not emerged. However, CDF has reported observation of several events of the second type which also have one of the jets identified as arising from a b–quark. The jets in these events have very large E_T. These events have *no* appreciable standard–model physics source other than $\bar{t}t$ production [3]. In this Letter, we presume that these $\bar{t}t$ candidate events are, in fact, real. We assume that the top–quark mass is 170 GeV, near the central value extracted from precision electroweak measurements at LEP [4].

The purpose of this Letter is to point out that the $\bar{t}t$ rates and associated pair–mass and momentum distributions measured in these Tevatron experiments may probe flavor physics which is beyond the standard model. Top–quark production can be significantly modified from QCD expectations by the resonant production of *colored*, flavor–sensitive scalar particles with mass in the range $400 - 500\,\mathrm{GeV}$.[2] In particular, we emphasize that the color–octet technipion, η_T, expected to occur in multiscale models [6], [7] of walking technicolor [8], [9], [10] can easily double the $\bar{t}t$ rate. The η_T occurs in technicolor models which have color–triplet techniquarks [11]. The production in hadron collisions via gluon fusion of a "standard" η_T—the one occurring in a one–family technicolor model and having decay constant $F = 123\,\mathrm{GeV}$ and nominal couplings to quarks and gluons—has been extensively discussed elsewhere [12] [13]. We shall see that the standard η_T with $M_{\eta_T} \sim 400\,\mathrm{GeV}$ increases the $\bar{t}t$ rate by only 15%. Because of uncertainties in QCD corrections to the standard–model $\bar{t}t$ rate, this is unlikely to be observable. In multiscale models, however, the η_T decay constant is much smaller, $F \sim 20 - 40\,\mathrm{GeV}$. For $M_{\eta_T} = 400 - 500\,\mathrm{GeV}$, this small decay constant is what accounts for a measurably larger $\bar{t}t$ rate.

[1] The integrated luminosity collected by CDF is $22\,\mathrm{pb}^{-1}$; for DØ it is $15\,\mathrm{pb}^{-1}$.

[2] C. Hill and S. Parke recently considered the effect on the $\bar{t}t$ rate of color–singlet and octet vector resonances that couple strongly to top quarks[5].

If an η_T with multiscale dynamics produces an excess of $\bar{t}t$ events, then there also must appear color–octet technirhos, ρ_T, which have flavor–blind couplings to quarks and gluons. The models discussed in Refs. [6], [7] indicate that they have mass in the range $200-600\,\mathrm{GeV}$. It is quite possible that at least one of these ρ_T decays predominantly into gg and $\overline{q}q$, and appears as a resonance in ordinary dijet production. In addition to the η_T, there will be other flavor–sensitive scalars—technipions, π_T—which are color octets and, possibly, color–triplets (leptoquarks). They have masses in the same general range as the η_T and the ρ_T.[3] They are strongly pair–produced in the Tevatron Collider experiments and their rates are enhanced if the decays $\rho_T \to \pi_T\pi_T$ are allowed. Thus, the hallmark of the new physics signalled by excess $\bar{t}t$ events is the appearance of colored technihadrons: scalars that are flavor–sensitive and vectors that may be flavor–blind. In addition, there will be color–singlet technihadrons, some decaying into W and Z–bosons. These were discussed in Ref. [6]. We urge searches for all these states as soon as possible.

In standard ETC models, the mass of the η_T arises mainly from QCD interactions (see S. Dimopoulos in Ref. [11]). For example, suppose that the technicolor group is $SU(N_{TC})$, that the technifermions transform according to the fundamental representation, $\mathbf{N_{TC}}$, and that they consist of one doublet of QCD–color triplet techniquarks, $Q=(U,D)$, and N_D-3 doublets of color–singlet technileptons, $L_i=(N_i,E_i)$. Then, the mass of the η_T has been estimated to be $M_{\eta_T} = 240\sqrt{N_D/N_{TC}}\,\mathrm{GeV}$. In walking technicolor models, proposed to suppress flavor–changing neutral currents while maintaining reasonable quark masses, there is a large and probably dominant ETC contribution to M_{η_T} [7].

The η_T is expected to decay predominantly into $\bar{t}t$, $\bar{b}b$ and gg. So long as the η_T is an approximate Goldstone boson, the amplitude for $\eta_T \to gg$ is reliably calculated from the Adler–Bell–Jackiw triangle anomaly. For one doublet of techniquarks in the $\mathbf{N_{TC}}$ representation of $SU(N_{TC})$,[4]

$$A(\eta_T^a(p) \to g_b(p_1)\,g_c(p_2)) = \frac{\alpha_s(M_{\eta_T})\,N_{TC}\,d_{abc}}{2\pi\sqrt{2}\,F_Q}\,\epsilon_{\mu\nu\lambda\rho}\epsilon_1^\mu\epsilon_2^\nu p_1^\lambda p_2^\rho\,. \tag{1}$$

Here, F_Q is the decay constant of technipions in the $\overline{Q}Q$ sector. If the only technifermions are techniquarks and technileptons comprising N_D doublets, then $F_Q \cong F_\pi/\sqrt{N_D}$ where

[3] We expect that these technipions are so heavy that the decay $t \to \pi_T b$ is forbidden.

[4] See, e.g., Ref. [12] and references therein. This amplitude may be modified by a form factor for the process $\eta_T \to g\rho_T$; $\rho_T \to g$. We do not expect this effect to change our conclusions significantly.

$F_\pi = 246\,\mathrm{GeV}$. The amplitude for $\eta_T \to \overline{q}q$ is more dependent on the details of the particular ETC model. The coupling to $\overline{q}q$ is expected to be approximately m_q/F_Q. To take into account ETC-model dependence, we introduce a dimensionless factor C_q, expected to be not much different from one, and write

$$A(\eta_T^a(p) \to q(p_1)\,\overline{q}(p_2)) = \frac{C_q\, m_q}{F_Q}\, \overline{u}_q(p_1)\,\gamma_5\, \frac{\lambda_a}{2}\, v_q(p_2)\,. \tag{2}$$

Then the η_T decay rates are

$$\begin{aligned} \Gamma(\eta_T \to gg) &= \frac{5\alpha_s^2\, N_{TC}^2\, M_{\eta_T}^3}{384\,\pi^3\, F_Q^2}\,; \\ \Gamma(\eta_T \to \overline{q}q) &= \frac{C_q^2\, m_q^2\, M_{\eta_T}\, \beta_q}{16\pi F_Q^2}\,. \end{aligned} \tag{3}$$

Here, $\beta_q = \sqrt{1 - 4m_q^2/M_{\eta_T}^2}$. For a one-family ETC model with $M_{\eta_T} = 400\,\mathrm{GeV}$, the η_T decay rates are $\Gamma(\eta_T \to \overline{t}t) = 8.0\,\mathrm{GeV}$, $\Gamma(\eta_T \to \overline{b}b) = 0.013\,\mathrm{GeV}$, and $\Gamma(\eta_T \to gg) = 0.28\,\mathrm{GeV}$.[5]

At the Tevatron Collider with $\sqrt{s} = 1800\,\mathrm{GeV}$, and with large m_t, standard $\overline{t}t$ production is dominated by light $\overline{q}q$ annihilation [14]. Using the EHLQ Set 1 distribution functions to compute the $\overline{t}t$ rate from the lowest–order cross sections, we find $\sigma(\overline{p}p \to \overline{t}t) = 3.6\,\mathrm{pb}$ for $m_t = 170\,\mathrm{GeV}$. Next–to–leading–log corrections and soft–gluon resummation [15] give rates which are 50% larger than these in this general top–mass range. Accordingly, throughout this paper we scale our computed $\overline{t}t$ cross sections by a factor of 1.5. So long as the η_T is relatively narrow, the process $gg \to \eta_T \to \overline{t}t$ does not interfere (in lowest order) with the purely QCD production processes. The differential cross section at subprocess center–of–mass energy $\sqrt{\hat{s}}$ is given by[6]

$$\frac{d\hat{\sigma}(gg \to \eta_T \to \overline{t}t)}{dz} = \frac{\pi}{4}\, \frac{\Gamma(\eta_T \to gg)\, \Gamma(\eta_T \to \overline{t}t)}{(\hat{s} - M_{\eta_T}^2)^2 + \hat{s}\,\Gamma^2(\eta_T)}\,. \tag{4}$$

Here, $z = \cos\theta$, where θ is the subprocess c. m. scattering angle. Combining this formula with the lowest–order QCD cross sections, and using the parameters assumed above, we

[5] The parameters used here are $m_t = 170\,\mathrm{GeV}$, $m_b = 5\,\mathrm{GeV}$, $\alpha_s(M_{\eta_T}) = 0.1$, $N_{TC} = 4$, $F_Q = 123\,\mathrm{GeV}$, and $C_b = C_t = 1$.

[6] In Eq. (5), we are using partially $\hat{s}$-dependent widths, with $\beta_t = \sqrt{1 - 4m_t^2/\hat{s}}$ and $\alpha_s = \alpha_s(\sqrt{\hat{s}})$.

find a total $\bar{t}t$ rate of 4.1 pb, to which η_T contributes only 0.54 pb. We assume that higher-order QCD corrections increase $\hat{\sigma}(gg \to \eta_T \to \bar{t}t)$ by the same amount as they do the QCD cross sections.[7] Then, the standard η_T probably has no observable effect on $\bar{t}t$ production.

To understand why multiscale technicolor implies a much larger $\eta_T \to \bar{t}t$ rate, let us examine $\sigma(\bar{p}p \to \eta_T \to \bar{t}t)$. For a relatively narrow η_T, it is given by

$$\sigma(\bar{p}p \to \eta_T \to \bar{t}t) \simeq \frac{\pi^2}{2s} \frac{\Gamma(\eta_T \to gg)\,\Gamma(\eta_T \to \bar{t}t)}{M_{\eta_T}\,\Gamma(\eta_T)} \int_{-Y_B}^{Y_B} dy_B\, z_0\, f_g^{(p)}(\sqrt{\tau}e^{y_B})\, f_g^{(p)}(\sqrt{\tau}e^{-y_B})\,. \tag{5}$$

In Eq. (5), $f_g^{(p)}$ is the gluon distribution function in the proton, $\tau = M_{\eta_T}^2/s$, y_B is the boost rapidity of the subprocess frame, and z_0 is the maximum value of $z = \cos\theta$ allowed by kinematics and fiducial cuts [12]. The key point of Eq. (5) is that, unless the $\eta_T \bar{t}t$ strength factor $C_t \lesssim 0.2$, the cross section is simply proportional to $\Gamma(\eta_T \to gg)$ and the form of this decay rate is fairly model-independent: it depends only on the technicolor and color representations of the η_T and on F_Q. In our case, it is proportional to N_{TC}^2/F_Q^2. Thus, the small decay constant of the η_T in multiscale technicolor implies a large $\sigma(\bar{p}p \to \eta_T \to \bar{t}t)$.

The multiscale model studied in Ref. [7] has many theoretical and phenomenological difficulties (not the least of which is obtaining a large top–quark mass unless one invokes near-critical extended technicolor interactions [16]). It is not our intention here to advocate adoption of the model in detail. However, to focus our discussion, we extract from it that there is one doublet of techniquarks, perhaps one or more doublets of technileptons, and the associated spectrum of technipions and technirhos at a scale that is relatively low compared to the electroweak breaking scale. Details of the high–scale technifermions, those most directly responsible for electroweak symmetry breaking, are not important for our considerations.

In the remainder of this Letter, we generally assume that $F_Q = 40\,\mathrm{GeV}$. We consider two cases for the $\eta_T \bar{t}t$ coupling: $C_t = 1$ and $C_t = \frac{1}{3}$, both with $m_t = 170\,\mathrm{GeV}$. The number of technicolors will be $N_{TC} = 4$ and we use $M_{\eta_T} = 400 - 500\,\mathrm{GeV}$ to study the effect of the η_T mass on the distributions of the $\bar{t}t$ invariant mass, $\mathcal{M}_{\bar{t}t}$

Figures 1 and 2 show the invariant mass distributions, $d\sigma(\bar{p}p \to \bar{t}t)/d\mathcal{M}_{\bar{t}t}$, to lowest order in QCD for $M_{\eta_T} = 400\,\mathrm{GeV}$ and $C_t = 1$ and $\frac{1}{3}$. The total cross section as well as

[7] For standard $\bar{t}t$ production, higher order QCD corrections to the $gg \to \bar{t}t$ amplitude are significantly larger than to the $\bar{q}q \to \bar{t}t$ amplitude [15]. Since the production of the η_T is in the symmetric color–octet gg channel, our assumption may be conservative.

its QCD and η_T components are shown. No cut is put on the top-quark rapidity. The η_T widths and integrated cross sections are summarized in Table 1.[8] The decay constant we chose, $F_Q = 40\,\mathrm{GeV}$, is at the upper end of the values found in the multiscale model calculations. Thus, an η_T in this mass range easily can double the $\bar{t}t$ production rate. In the absence of the η_T, we calculate the mean $\mathcal{M}_{\bar{t}t}$ for a 170 GeV top quark to be 430 GeV. The closer the η_T is to the $\bar{t}t$ threshold, the lower is this $\langle\mathcal{M}_{\bar{t}t}\rangle$.

These invariant mass distributions and rates convey a qualitative impression of the effect of varying the η_T mass and width. Because the main production mechanisms at the Tevatron energy, $\bar{q}q \to \bar{t}t$ and $gg \to \eta_T \to \bar{t}t$, are central, the p_T distributions for the top quarks are expected to have a shape similar to Figs. 1–2, with $p_T(t) = |\sum_{t\to \mathrm{jets}} \vec{p}_T(\mathrm{jet})| \simeq 0.5 m_t$. Detailed event and detector simulations are needed to determine the best variables to test for the presence of the η_T in the existing data and in higher–luminosity samples.

If the η_T of multiscale technicolor exists, there will also be color–octet ρ_T and π_T in the same general mass region and they will, in principle, be observable in the Tevatron experiments. Their signatures are more dependent on the details of the model than the η_T signatures are. We briefly discuss two general cases, distinguished by whether techni–isospin (I_T) breaking is negligible or not. In both cases we assume that there is at least one doublet of technileptons $L = (N, E)$, so that there are color–triplet (leptoquark), as well as octet, technipions. We denote the two types by $\pi_{\overline{Q}L}$, $\pi_{\overline{L}Q}$ and $\pi_{\overline{Q}Q}$, respectively.

If I_T–breaking is small, the techniquark hard masses satisfy $m_Q \equiv m_U \cong m_D$. Similarly, $m_L \equiv m_N \cong m_E$. Then, all $\pi_{\overline{Q}Q}$ are degenerate, as are all leptoquarks and all octet ρ_T. If we ignore QCD contributions, their masses are given by [6],[7]

$$\begin{aligned} M^2_{\pi_{\overline{Q}Q}} &\simeq 2 m_Q \, \langle \overline{Q}Q \rangle_{\Lambda_Q} / F_Q^2 \,, \\ M^2_{\pi_{\overline{Q}L}} &\simeq (m_Q + m_L)\, \langle \overline{Q}Q \rangle_{\Lambda_Q} / F_Q^2 \,, \\ M_{\rho_T} &\simeq 2\,(m_Q + \Lambda_Q) \,. \end{aligned} \tag{6}$$

Here, Λ_Q is the techniquark condensation scale; we relate it to the η_T decay constant by $\Lambda_Q \simeq F_Q\,(\frac{1}{2} M_\rho / f_\pi) = 165\,\mathrm{GeV}$ for $F_Q = 40\,\mathrm{GeV}$. The techniquark condensate (renormalized at Λ_Q) is estimated to be $\langle \overline{Q}Q \rangle_{\Lambda_Q} \simeq 4\pi F_Q^3$. These mass formulae are true regardless of the size of I_T–breaking. They imply simple sum rules which can be employed should candidates for the π_T and ρ_T ever be found. For example, note that $M_{\pi_{\overline{Q}L}} \geq M_{\pi_{\overline{Q}Q}}/\sqrt{2}$.

[8] It is clear from the table that, for the parameters we used, the narrow–width approximation of Eq. (5) is only approximately satisfied.

For $M_{\eta_T} = 400\,\mathrm{GeV}$, we obtain $m_Q \simeq 160\,\mathrm{GeV}$ and $M_{\rho_T} \simeq 650\,\mathrm{GeV}$. The color–octet technipion decay channels of ρ_T are closed. The leptoquark channels are also closed *if* $m_L > 0.32\, m_Q \simeq 50\,\mathrm{GeV}$.

If the ρ_T lies below the two–technipion threshold, it decays mainly into $\overline{q}q$ and gg dijets. With ρ_T–coupling parameters chosen as in Ref. [7], the ρ_T is narrow, $\Gamma(\rho_T \to 2\,\mathrm{jets}) \simeq 12\,\mathrm{GeV}$.[9] We calculated the excess dijet cross section in the vicinity of $\mathcal{M}_{\rm jj} = 650\,\mathrm{GeV}$ to be $2.5 - 1.0\,\mathrm{pb}$. This sits on a background of $1.0\,\mathrm{pb}$. Radiative corrections have not been applied. The range of variation in the signal includes an estimate of the effect of jet–energy resolution, which is about 5% for CDF at $\mathcal{M}_{\rm jj} = 650\,\mathrm{GeV}$ [17]. Observation of this dijet resonance will require very high integrated luminosity at the Tevatron.

The ρ_T width will be dominated by the leptoquark decay channels if they are open. The leptoquarks are themselves expected to decay as $\pi_{\overline{N}U} \to \overline{\nu}t$, $\pi_{\overline{E}U} \to \tau^+ t$, $\pi_{\overline{N}D} \to \overline{\nu}b$, and $\pi_{\overline{E}D} \to \tau^+ b$. Again, the cross sections are only in the few pb range, depending on the number of technileptons and the masses of the leptoquarks.

Consider now the case that I_T–breaking is appreciable. The ρ_T and π_T will be approximately ideally–mixed states. For example, the electrically–neutral color–octets appear as $\overline{U}U$ and $\overline{D}D$ states instead of $(\overline{U}U + \overline{D}D)/\sqrt{2}$ and $(\overline{U}U - \overline{D}D)/\sqrt{2}$. Thus, there are now two "η_T" produced in gg fusion: $\pi_{\overline{U}U}$ decaying mainly to $\overline{t}t$ and $\pi_{\overline{D}D}$ decaying mainly to gg (unless the factor $C_b \gg 1$). We expect $m_U > m_D$, hence $M_{\pi_{\overline{U}U}} > M_{\pi_{\overline{D}D}}$. The effect on the η_T decay amplitudes is to multiply $A(\eta_T \to gg)$ by $1/\sqrt{2}$ and $A(\eta_T \to \overline{q}q)$ by $\sqrt{2}$, changes that can be hidden in the magnitude of F_Q and C_q. There will be no measurable enhancement of the dijet rate due to $\overline{p}p \to \pi_{\overline{D}D} \to gg$.

In Ref. [7], it was found that the $\rho_{\overline{U}U}$ generally was above $\pi_T\pi_T$ threshold. Whether the lighter $\rho_{\overline{D}D}$ lay above or below the threshold was dependent on calculational details. To illustrate one possible scenario, we have considered the case $M_{\rho_{\overline{D}D}} \simeq 375\,\mathrm{GeV} < 2M_{\pi_T}$ and $M_{\rho_{\overline{U}U}} \simeq 500\,\mathrm{GeV} > 2M_{\pi_T}$.[10] The signal and background dijet cross sections are shown in Fig. 3 and, with a dijet mass resolution of about 7%, in Fig. 4. Also shown in Fig. 3 are the ρ_T signal in the $\overline{b}b$ channel. The jet rapidities were required to be less than 0.7. Such a tight cut is necessary to observe the central–region signal.

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[9] In Ref. [7] we used $\Gamma(\rho_T^a \to g^a \to gg) : \Gamma(\rho_T^a \to g^a \to \overline{q}_i q_i) = 3:1$. We expect that if observable ETC modifications of these results occur, they will be flavor–symmetric. We thank R. S. Chivukula for bringing this issue to our attention.

[10] The technipion masses were taken to be $M_{\overline{U}U} = 400\,\mathrm{GeV}$, $M_{\overline{U}D} = 325$, $M_{\overline{D}D} = 225$, $M_{\pi_{\overline{N}U}} = 300$, $M_{\pi_{\overline{N}D}} = M_{\pi_{\overline{E}U}} = 250$, and $M_{\pi_{\overline{E}D}} = 200$.

The $\rho_{\overline{D}D}$ true width is about 3 GeV. The integral, from 360 GeV to 400 GeV, over the resonant cross section is 70 pb, while the background is 50 pb (that is, a signal–to–background ratio of $S/B = 20\,\mathrm{pb}/50\,\mathrm{pb}$). The CDF jet–energy resolution deteriorates this S/B significantly. The integrals, from 325 GeV to 425 GeV, over the total and background cross sections in Fig. 4 are 145 pb and 130 pb, respectively. The S/B in the (unsmeared) $\overline{b}b$ signal is much higher than for the total dijet cross section: $2.7\,\mathrm{pb}/0.5\,\mathrm{pb}$.[11] However, to take account of this enhancement with an integrated luminosity of $50-100\,\mathrm{pb}^{-1}$ requires a b-jet identification and reconstruction efficiency of at least 25%. Finally, in this case the $\rho_{\overline{U}U}$ resonance is practically invisible in the dijet signal. It must be sought in $\rho_{\overline{U}U} \to \pi_T\pi_T$. Typical rates are discussed in Ref. [7]. Efficient heavy-flavor (t, b, τ) tagging will be essential.

In this Letter, we have reëmphasized that multiscale technicolor has low–energy degrees of freedom that can significantly enhance the rates of heavy–flavor processes under study at the Tevatron Collider. The color–octet η_T of multiscale technicolor, with its small decay constant, $F_Q = 30-40\,\mathrm{GeV}$, can easily double the top–quark production rate and skew its distributions. Color–octet ρ_T may lie below technipion threshold and appear as narrow resonances in dijet production. If $\rho_T \to \pi_T\pi_T$ occurs, the technipions may be sought via their expected decay to heavy quarks and leptons. If the basic ideas of multiscale technicolor underlie the physics of electroweak symmetry breaking, a broad spectrum of measurements will be needed at the Tevatron to limit scenarios and help pin down basic parameters. The discovery of the high–scale technihadrons most directly linked to electroweak symmetry breaking must await high–luminosity multi–TeV colliders. However, the Tevatron Collider experiments may herald the true beginning of our understanding of flavor physics.

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[11] We thank Frank Paige for suggesting that the $\overline{b}b$ channel would have a better S/B than the gluon and light quark channels.

References

[1] CDF Collaboration: F. Abe, et al., FERMILAB–PUB–Conf–93/212–E (1993); T. Chikamatsu, “Search for the Top Quark in the Dilepton Channel at CDF”, and M. Contreras, “Top Search in the Lepton plus Jets Channel at CDF”, in “Proceedings of the 9^{th} Topical Workshop in $\overline{p}p$ Collider Physics”, Tsukuba (1993), ed. by K. Kondo.

[2] D0 Collaboration: M. Strovink, “Proceedings of the International Europhysics Conference on High Energy Physics”, Marseille (1993), eds. J. Carr and M. Perrottet; M. Fatyga, “Search for the Top Quark at DØ (in the di-lepton channels)” and H. Greenlee, “Search for the Top Quark in the Single Lepton Plus Jets Channel at CDF”, in “Proceedings of the 9^{th} Topical Workshop in $\overline{p}p$ Collider Physics”, Tsukuba (1993), ed. by K. Kondo.

[3] J. M. Benlloch, K. Sumorok, and W. Giele, “Possibilities of Discovering a Heavy Top Quark in the Lepton-Multijet Channel”, FERMILAB–Pub–93/276–T (1993) and references therein.

[4] W. Hollik, “Status of the Electroweak Standard Model”, presented at the XVI International Symposium on Lepton-Photon Interactions, Cornell University, Aug. 10-15, 1993, Ithaca, NY.

[5] C. Hill and S. Parke, FERMILAB–Pub–93/397–T.

[6] K. Lane and E. Eichten, Phys. Lett. **222B** (1989) 274.

[7] K. Lane and M V. Ramana, Phys. Rev. **D44** (1991) 2678.

[8] S. Weinberg, Phys. Rev. **D13**(1976) 974; *ibid*, **D19** (1979) 1277;
L. Susskind, Phys. Rev. **D20** (1979) 2619.

[9] S. Dimopoulous and L. Susskind, Nucl. Phys. **B155** (1979) 237;
E. Eichten and K. Lane, Phys. Lett. **90B** (1980) 125.

[10] B. Holdom, Phys. Rev. **D24** (1981) 1441; Phys. Lett. **150B** (1985) 301 ;
T. Appelquist, D. Karabali and L. C. R. Wijewardhana, Phys. Rev. Lett. **57** (1986) 957 ; T. Appelquist and L. C. R. Wijewardhana, Phys. Rev. **D36** (1987) 568 ;
K. Yamawaki, M. Bando and K. Matumoto, Phys. Rev. Lett. **56**, (1986) 1335 ;
T. Akiba and T. Yanagida, Phys. Lett. **169B** (1986) 432.

[11] E. Farhi and L. Susskind Phys. Rev. **D20** (1979) 3404;
S. Dimopoulos, Nucl. Phys. **B168** (1980) 69 ;
T. Appelquist and J. Terning, Yale and Boston University Preprint YCTP-P21-93, BUHEP-93-23 (1993).

[12] E. Eichten, I. Hinchliffe, K. Lane and C. Quigg, Rev. Mod. Phys. **56** (1984) 579; *ibid*, Phys. Rev. **34** (1986) 1547.

[13] T. Appelquist and G. Triantaphyllou, Phys. Rev. Lett. **69** (1992) 2750.

[14] P. Nason, S. Dawson, and R. K. Ellis, Nucl. Phys. **B303** (1988) 607; W. Beenakker, H. Kuijf, W. L. van Neerven and J. Smith, Phys. Rev. **D40** (1989) 54.

[15] E. Laenen, J. Smith and W. L. Van Neerven, Nucl. Phys. **B369** (1992) 543; *ibid*, FERMILAB–Pub–93/270–T.

[16] T. Appelquist, T. Takeuchi, M. B. Einhorn, L. C. R. Wijewardhana, Phys. Lett. **220B** (1989) 223; T. Takeuchi, Phys. Rev. **D40** (1989) 2697 ;
V. A. Miransky and K. Yamawaki, Mod. Phys. Lett. **A4** (1989) 129

[17] F. Abe, et al. Phys. Rev. **D48** (1993) 999.

M_{η_T}	C_t	$\Gamma(\eta_T \to \bar{t}t)$	$\Gamma(\eta_T \to gg)$	$\sigma_{\rm tot}(\bar{t}t)$	$\sigma_{\eta_T}(\bar{t}t)$	$\langle \mathcal{M}_{\bar{t}t} \rangle$
400	1	76	2.88	11.4	5.87	410
400	$\frac{1}{3}$	8.4	2.88	11.5	5.96	415
450	1	106	3.99	9.21	3.70	425
450	$\frac{1}{3}$	11.8	3.99	8.38	2.86	435
500	1	132	5.35	7.98	2.46	430
500	$\frac{1}{3}$	14.6	5.35	6.90	1.39	440

TABLE 1: η_T widths, $\bar{t}t$ cross sections in $\bar{p}p$ collisions at 1800 GeV, and mean $\mathcal{M}_{\bar{t}t}$. The top quark mass is 170 GeV. The η_T decay constant is $F_Q = 40\,\mathrm{GeV}$. Masses and widths are in GeV; cross sections are in picobarns. QCD radiative corrections have been estimated by multiplying cross sections by 1.5.

Figure Captions

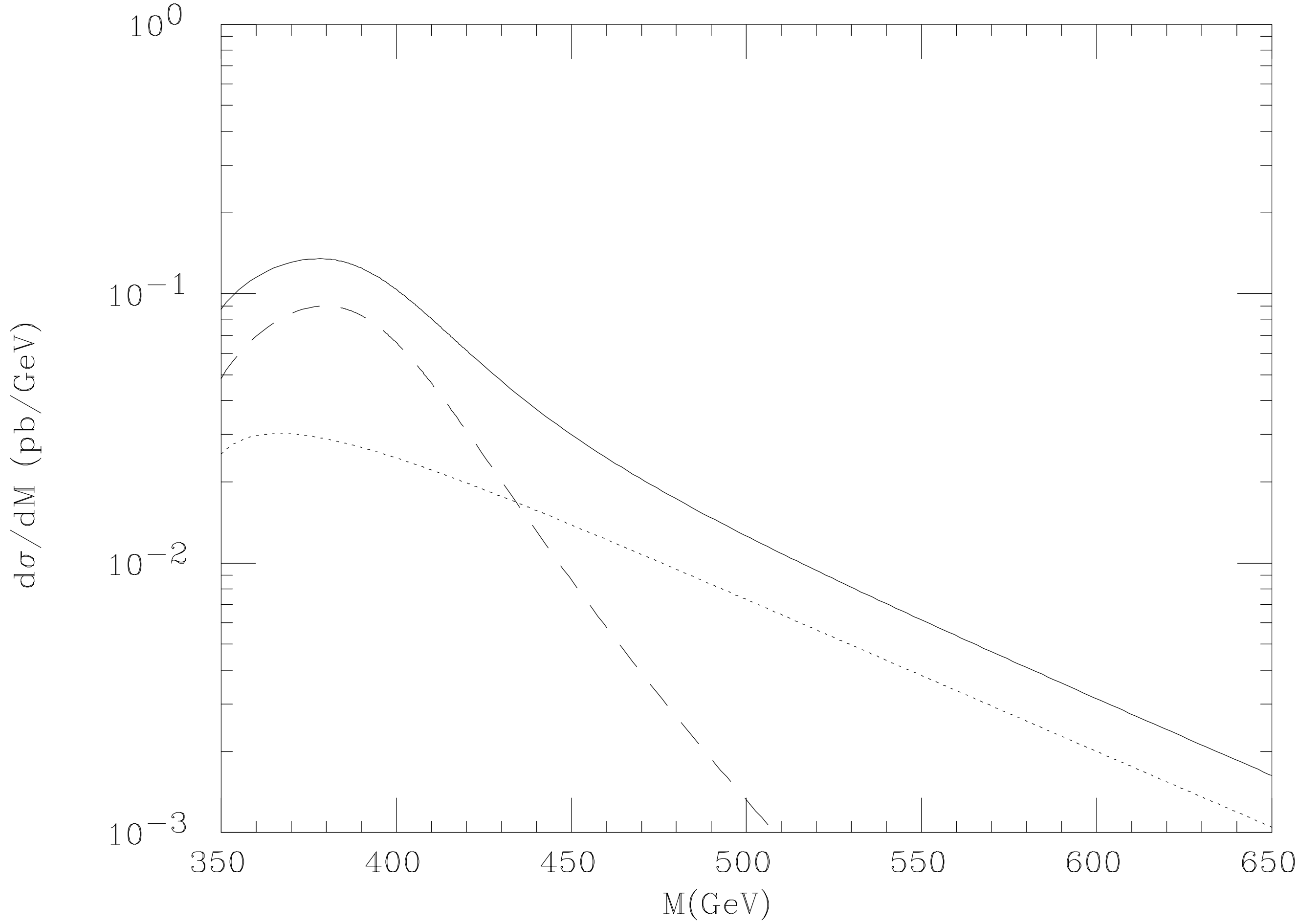
[1] The $\bar{t}t$ invariant mass distribution for $M_{\eta_T} = 400\,\mathrm{GeV}$ and $C_t = 1$ in $\bar{p}p$ collisions at $\sqrt{s} = 1800\,\mathrm{GeV}$. The QCD (dotted curve), $\eta_T \to \bar{t}t$ (dashed), and total (solid) rates have been multiplied by 1.5 as explained in the text.

[2] The $\bar{t}t$ invariant mass distribution for $M_{\eta_T} = 400\,\mathrm{GeV}$ and $C_t = \frac{1}{3}$ in $\bar{p}p$ collisions at $\sqrt{s} = 1800\,\mathrm{GeV}$. Curves are labeled as in Fig. 1.

[3] The invariant mass distributions for dijets (upper curves) and $\bar{b}b$ (lower curves) in $\bar{p}p$ collisions at $\sqrt{s} = 1800\,\mathrm{GeV}$. The solid curves include the $\rho_{\overline{D}D}$ and $\rho_{\overline{U}U}$ resonances at 375 and 500 GeV. The dashed curves show the standard QCD distributions. Radiative corrections have not been applied.

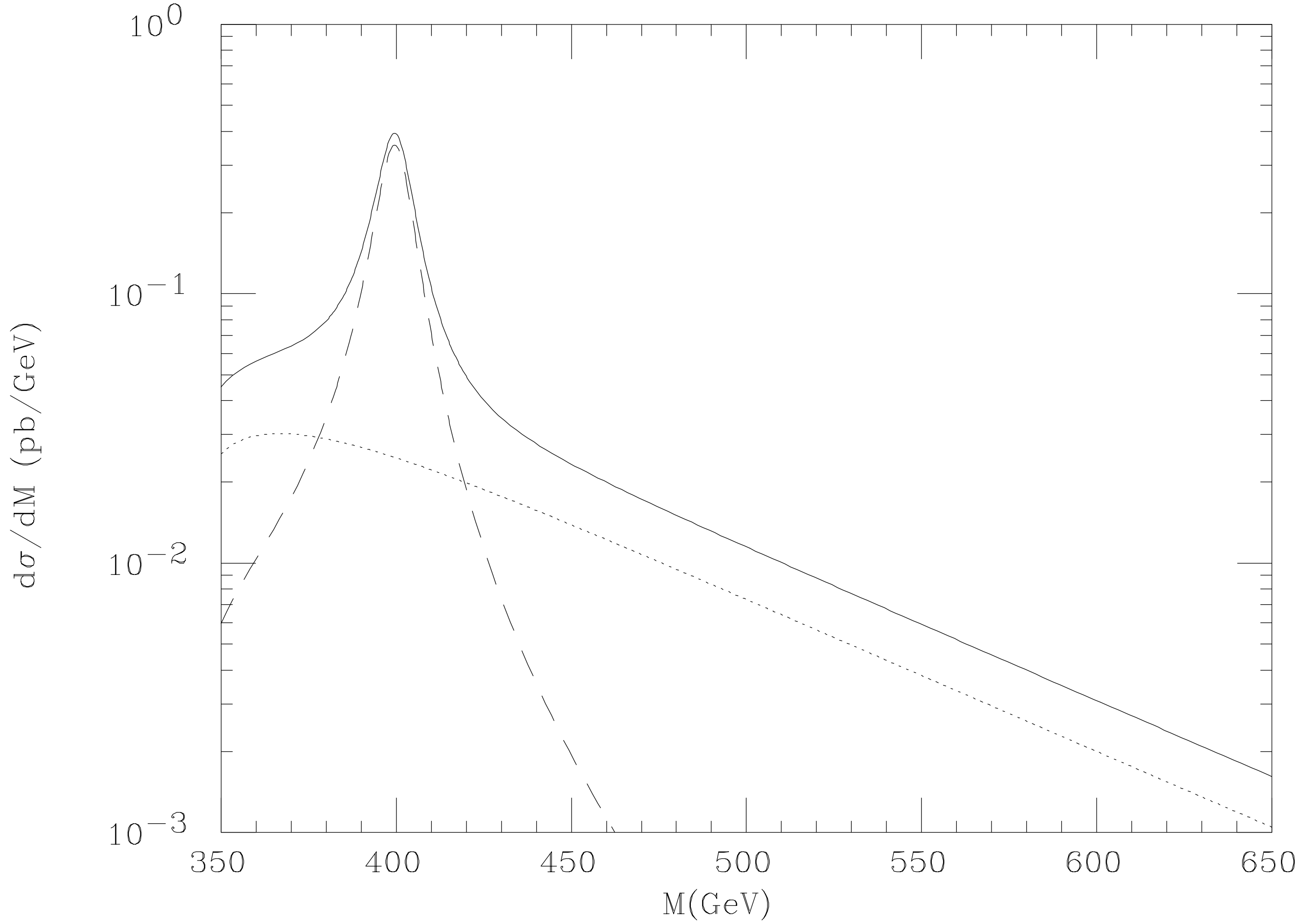
[4] The dijet mass distributions as in the upper curves of Fig. 3, except that a uniform resolution smearing of $\Delta\mathcal{M}/\mathcal{M} = 7\%$ has been applied.

FIGURE 1



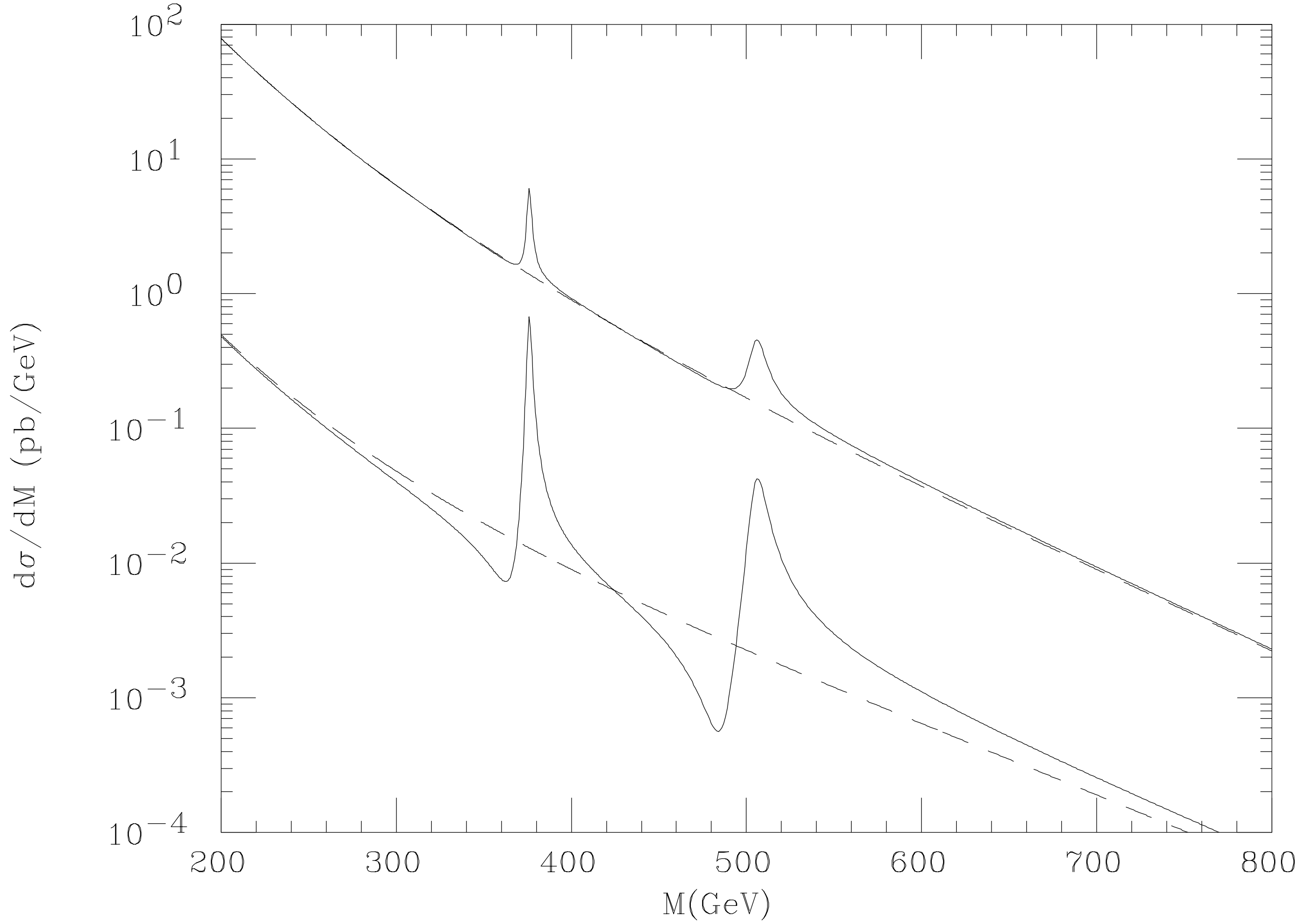
10^0
10^{-1}
10^{-2}
10^{-3}
$d\sigma/dM$ (pb/GeV)
350
400
450
500
550
600
650
M(GeV)

FIGURE 2



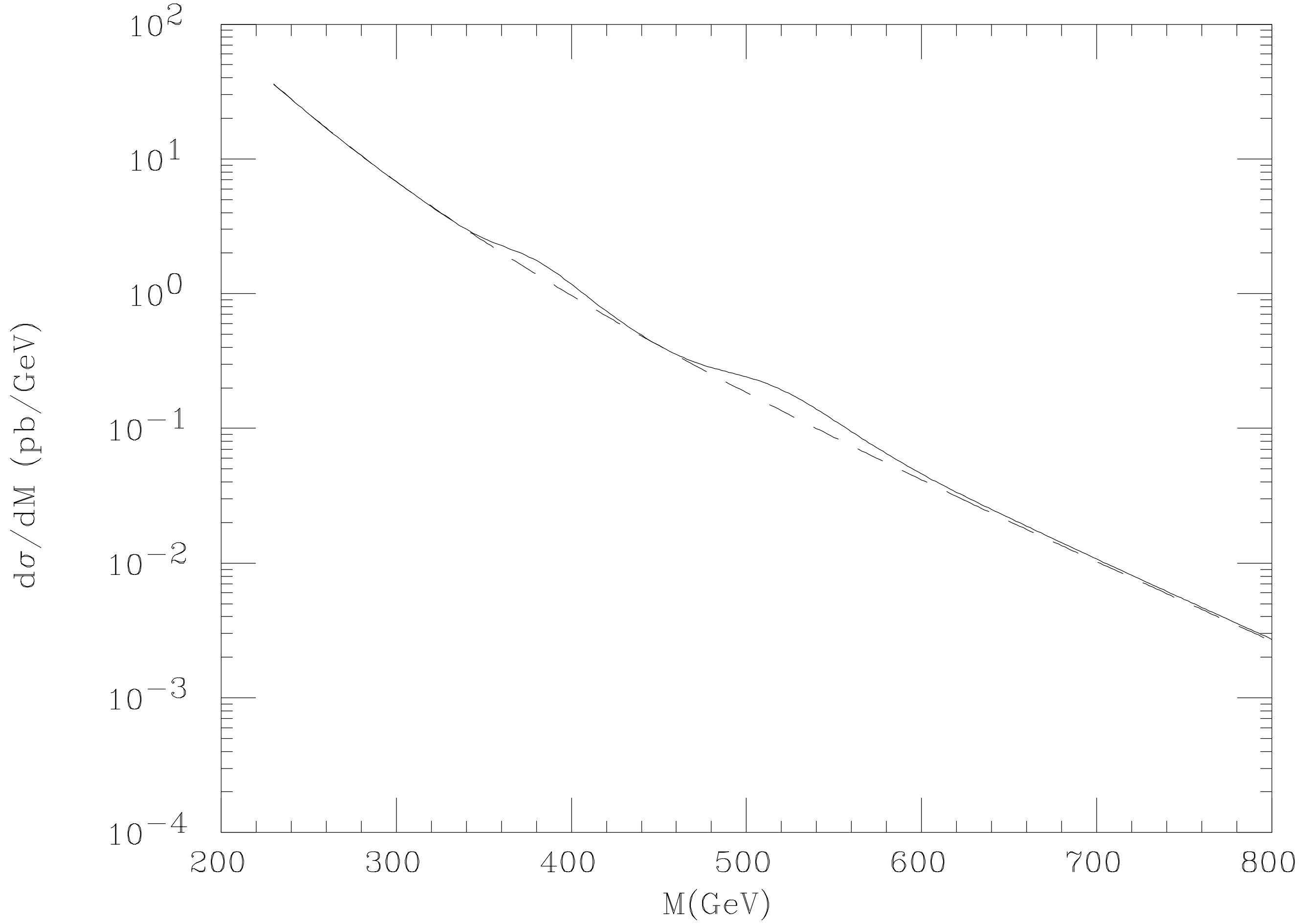
10^0
10^{-1}
10^{-2}
10^{-3}
$d\sigma/dM$ (pb/GeV)
350
400
450
500
550
600
650
M(GeV)

FIGURE 3



10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$d\sigma/dM$ (pb/GeV)
200
300
400
500
600
700
800
M(GeV)

FIGURE 4



10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$d\sigma/dM$ (pb/GeV)
200
300
400
500
600
700
800
M(GeV)